A supply chain taxonomy for blood products

A SUPPLY CHAIN TAXONOMY FOR BLOOD PRODUCTS

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Introduction

The Scottish National Blood Transfusion Service (SNBTS) is a blood service organisation with sole responsibility for the collection, testing, processing and distribution of blood products across Scotland. A programme of restructuring to achieve greater productivity and efficiency includes the centralisation of testing and processing activities in a new National Processing Centre located in the central belt of Scotland due to open in 2017. This network restructuring presents an opportunity for the organisation to design a more resilient supply chain strategy for the future. This includes the development of a decision framework or taxonomy to support supply chain selection. Grouping products using appropriate product, demand and market characteristics will guide decision making around supply chain strategy allowing SNBTS managers to identify the best supply chain for different types of products that will ensure availability of life saving products whilst reducing the risk of wastage.

This paper first identifies the range of criteria used in devising a segmented supply chain strategy as described in the literature. A logical argument is presented to select those criteria most appropriate given the nature and purpose of the blood supply chain before applying the chosen criteria to segment products in a single case study focused on the Royal Infirmary Edinburgh Blood Bank.

Literature Review

Several authors have warned of the perils of misaligning products, customers and supply chains (Fisher,1997; Sun et al., 2009; Christopher and Towill, 2002) as failure to do so can lead to a loss of competitive advantage caused by degraded customer service levels, surplus inventory, escalating costs and declining profits or poor return on assets (Lee, 2002). Fisher (1997) outlines the steps that a company should take to develop an effective supply chain strategy by understanding the nature of demand for their products, with products being either functional or innovative. These two groups of products should have different supply chain strategies with a responsive or agile supply chain for innovative products and a physically efficient or lean supply chain for functional products. Building on Fisher's work Christopher and Towill (2002) devised a supply chain taxonomy that incorporates a third strategy, a Top-Up Agile pipeline which combines Lean and Agile approaches. Subsequently researchers have produced numerous examples ((Payne and Peters, 2004; Lovell et al., 2005; Rezaei and Ortt, 2012; Hübner et al., 2013 and others) of product and market (customer) driven segmentation to underpin supply chain strategy selection. A range of criteria to segment products and markets to suit different supply chain objectives have been discussed in the literature, a selection of these criteria are summarised in Table 1 and those relevant to this research are discussed below.

Category	Criterion	Authors
Product	Dollar-usage	
	Product Value Density	*Lovell et al. (2005)*
	Criticality	*Rutherford and Woolford (2005); Payne and Peters (2004)*
	Substitutability	*Payne and Peters (2004)*
	Shelf life	*Blackburn and Scudder (2009); Kittipanya-ngam et al. (2011)*
	Product variety	*Childerhouse et al. (2002)*
	Product life cycle	*Christopher and Peck (1999); Vonderembse et al. (2006); Jüttner et al. (2006); Childerhouse et al. (2002)*
Market	Location of demand	*Christopher and Towill (2002); Kittipanya-ngam et al. (2011)*
	Volume demand	*Payne and Peters (2004); Childerhouse et al. (2002)*
	Variability of demand/ Predictability of demand	*Payne and Peters (2004); Christopher and Towill (2002); Lovell et al. (2005); Childerhouse et al. (2002); Lee (2002); Sun et al. (2009);*
	Service level/availability	*Christopher and Towill (2002)*
Source	Supply uncertainty	*Lee (2002)*
	Operational capabilities	*Harrison and van Hoek (2005)*
	Economies of scale	*Harrison and van Hoek (2005)*

Table 1. Supply chain segmentation criteria

Product criteria

Economic criteria such as product value and 'dollar-usage' are essential segmentation criteria when looking to trade-off inventory, transportation and other logistical costs. Lovell et al. (2005) for example use Product Value Density (PVD) as the key segmentation criterion in the redesign of the Sony BPE supply chain. PVD is the ratio of product cost value to chargeable weight and is a useful determinant of transport modal choice and the placement of inventory holdings to minimise total logistics costs. In the context of blood products, economic criteria such as PVD would not be appropriate as there is relatively little variation in monetary value between blood products and indeed the cost value is far outweighed by the significant non-economic 'value' associated with the life-saving potential of blood products. Hence a non-economic criterion such as product 'criticality' as measured from a clinical (customer) perspective would be more appropriate to this research. Payne and Peters (2004) used substitutability as an indicator of criticality in the electronics industry and determined product substitutability by asking "if a product is out of stock, can the company supply another product to satisfy the customer", with 'A' products being non-substitutable and therefore critical to the customer. Rutherford and Woolford (2005) used criticality to segment aircraft spare parts defining criticality in terms of the impact a spare part shortage would have on aircraft availability. They engaged with expert RAF personnel to identify the determinants of 'criticality' and then used Saaty's Analytical Hierarchy Process (AHP) to produce a criticality rating system to divide parts into Vital, Essential and Desirable (VED) categories.

Product life cycle is another popular segmentation criterion (Childerhouse et al., 2002, Aitken et al., 2005, Godsell et al., 2011), however it would seem irrelevant to blood product supply as product life cycles are likely to be indefinite, at least until a viable alternative to human blood is developed. Product variety too, although a relevant criterion in commercial sectors where product variety can be high and variable, there is little variety in blood products. However, a particularly relevant criterion is product shelf life because blood products are perishable and range in shelf-life from 1 day to 3 years. Shelf life has been used by Blackburn and Scudder (2009) and Kittipanya-ngam et al. (2011) in their case studies of supply chain segmentation within the food industry.

Market criteria

Demand volume is by far the most common criterion used to segment products, often classified as a 'product criterion' we argue that the focus should rather be on customer specific demand volume; the same argument applies to the criterion of demand variability or uncertainty which is often used to match products to more agile supply chains (Fisher, 1997; Christopher and Towill, 2002). Customers that generate more predictable and high volume demand for a particular product warrant a more lean supply as the risk of over or under supply is reduced, whereas customers that demand low volumes of the same product in a more unpredictable pattern should be served by a more agile supply chain. Godsell et al. (2011) warn that using product criteria alone to inform supply chain strategy will not reflect the different needs of different customers; and understanding the buying behaviour of different markets (Godsell et al., 2006) is essential in order to design an appropriate customer responsive supply chain. Location of demand and replenishment lead time are also important in supply chain segmentation in terms of the strategic positioning of inventory and the decision to centralise or decentralise stocks. In the context of healthcare, several Scottish hospitals are in remote locations and hence risk uncertain replenishment lead-times, whilst others in the central belt are reliably within 30 minutes of the processing site. This market diversity should be considered when deciding on stock-holding points for different product –customer groups.

Source criteria

Production technologies often dictate whether a product can be supplied with a given lead-time or made-to-order (Christopher and Towill, 2002). In the blood supply chain, regulatory time constraints placed on the shelf life of certain products can put pressure on manufacturing to make-to-stock certain products within 24 hours or less of whole blood donation. For example, buffy coat granulocyte products will time expire at midnight on the day of whole blood collection (United Kingdom Blood Services, 2013). In effect as soon as a donation is made the supply chain must *push* the product to finished stock else waste the donor's gift. This has significant implications for supply chain segmentation as so few products can be made-to-order, it also points to the importance of supply (donor) management and the need to synchronise supply and demand as closely as possible. Lee (2002) discusses supply uncertainty in the context of the ability of an operational process to reliably produce products to satisfy market demand. Although blood processing is not considered a source of uncertainty the uncertainty of donor supply is a key issue for the blood service and much effort is made to recruit and retain a steady and reliable supply of donated blood that matches demand (Veldhuizen et al., 2013).

Methodology

To illustrate how segmentation using appropriate criteria can be used to devise a framework for blood product supply chain selection, this research presents a single case study of the blood supply chain incorporating one Scottish hospital blood bank, the Royal Infirmary Edinburgh (RIE). There are 30 blood banks in Scotland each located in a hospital; each blood bank supplies blood within its own hospital and many also supply satellite hospitals. The blood supply chain is as illustrated in Figure 1.

Figure 1. Outline schematic of the blood supply chain in Scotland

Data collection: In line with other researchers (Currie et al., 2004) transfused demand was identified as an indicator of true end customer demand. Daily transfused demand data for all blood products (red cells, platelets and plasma derived products) used by RIE and its satellite hospitals were extracted from the SNBTS archival data base into Microsoft Excel. In total 40 different products were transfused over a 12 month period. Other data pertaining to product substitutability, customer location, shelf-life and storage requirements were sourced from SNBTS documentation and via interviews with SNBTS experts.

Data analysis: Transfused demand data were cleansed with incomplete and anomalous data removed before applying segmentation criteria. Most segmentation methods are based on the Pareto principle and use ABC analysis to segment products (or customers) using a single criterion such as demand volume. In this research we use a multi-criteria approach following the method of Flores and Whybark (1986) to segment products by volume into ABC categories and also by 'criticality' into VED categories producing 9 overall segments. We also consider shelf-life and storage conditions when finally assigning products to different supply chain strategies. In this research product criticality is derived from a simple measure of substitutability and compatibility across the 8 ABO blood types. We define these two dimensions as follows:

Substitutability**:** *if a product is out of stock, can the patient be transfused with another product, if not then the product is non-substitutable and therefore 'critical'.* Products were scored from 7 (non-substitutable) to 0 (substitutable with all other blood groups).

Compatibility: *if a product can be transfused into patients of other blood groups then it is compatible and therefore more 'critical' than non-compatible products.* Products were scored 0 (non-compatible) to 7 (compatible with all other blood groups).

The degree of substitutability and compatibility of all red cell, platelet and plasma products across the 8 ABO blood groups was determined using tables published in the Handbook for Transfusion Medicine (United Kingdom Blood Services, 2013). For example, O-Negative Blood is regarded as the *Universal Donor* because it can be transfused into patients of any other ABO group, hence it has the highest compatibility score of 7, but in the event of shortage, O-Negative patients cannot receive any other blood group and hence O-Negative is non-substitutable and assigned a rating of 7. The criticality is simply the sum of these 2 ratings, i.e. 14, the highest possible criticality score. The different criteria and segments subsequently generated are shown in Table 2. Following product segmentation into ABC/VED segments a logical process was used to assign different segments to four supply chain strategies. The logic of the framework was validated by SNBTS experts to ensure the outcome is meaningful and that no product was assigned to an inappropriate supply channel.

Category	Criteria	Segments		
Product	Criticality	(V)ital –Critical products with a criticality score of 11 and over (E)ssential – Products with a criticality score of between 6 and 10 (D)esirable –Products with a score equal or less than 5		
	Shelf life & storage	• Short < 15 days Refrigerated/ambient	• Medium 15 to 35 days Refrigerated/ambient	• Long 2 or 3 years Frozen
Market	Delivery time	< 1 hour; 1 - 2 hours; 2 - 3 hours; > 3 hours		
	Volume demand	A – High volume: top 20% of products B – Medium volume: the following 30% of products C – Low volume: the remaining 50% of products		

Table 2. Segmentation criteria for blood products and markets

Findings and Discussion

Analysis of aggregate transfused demand across all Scottish hospitals revealed a strong Pareto relationship with 20% of products (A category) accounting for 95% of demand. The picture at individual Blood Bank level is different and varies from one Blood Bank to the next. Figure 2 is the Pareto curve of RIE product demand showing that 20% of products account for 80% of all transfused demand.

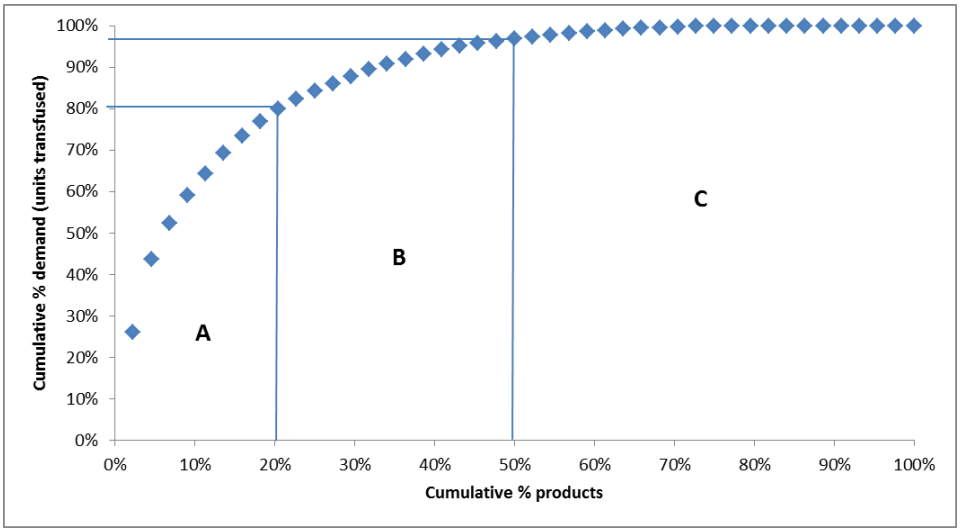

Figure 2. Pareto of blood products by transfused demand volume (RIE Blood Bank)

Following segmentation by demand volume and product criticality, an analysis of the results reveals the product split detailed in Table 2.

Segments		V	E	D	Totals
A	no. products	1	3	5	**9**
	demand (units)	*1,338*	*7,692*	*6,952*	*15,981*
B	no. products	3	6	3	**12**
	demand (units)	*964*	*1,623*	*769*	*3,355*
C	no. products	9	3	7	**19**
	demand (units)	*178*	*81*	*133*	*392*
	Total no. products	**13**	**12**	**15**	**40**
Total demand (units p.a)		*2,492*	*9,404*	*7,863*	***19,759***

Table 3. Product split and demand volume per ABC/VED segment (RIE Blood Bank)

The only VA product is O-Negative red cells which alone accounts for 7% of all RIE transfusions. However, it is perhaps surprising that the majority of Vital products are slow moving; these 9 VC products potentially present a problem for supply chain managers as customers will need high levels of on-shelf availability necessitating high safety stocks in each customer location and hence the risk of wastage due to shelf-life expiry will increase. For this reason it is important to consider shelf-life as well as delivery time (customer location) in addition to volume and criticality when deciding on a supply chain strategy. RIE's close proximity to the new National Processing Centre (less than 30 minutes) does mean that ad hoc deliveries could be part of an agile strategy to satisfy demand from central stocks for very slow moving V and E products which together account for just 1.3% of annual transfused demand. The general principle or logic applied when assigning our ABC/VED segments to

different supply chain strategies is illustrated in figure 3. The most vital fast moving products (VA segment) will be best served in a decentralised supply chain where the strategy is *make-to-stock* (MTS) based on an aggregate forecast and then *distribute-to-customer stock* based on a daily forecast of customer demand. It is essential that these products are immediately available at customer locations.

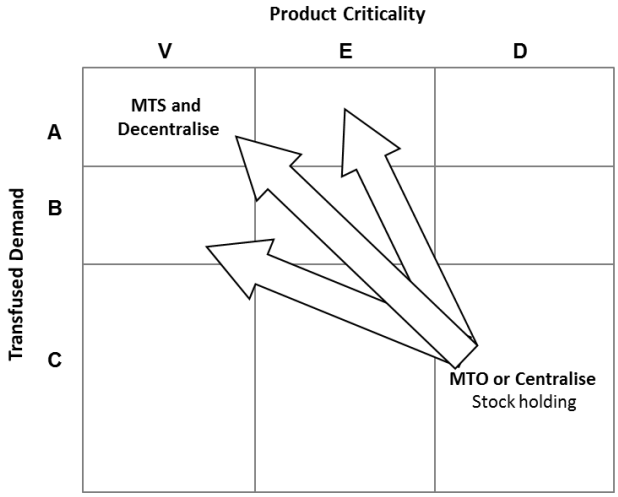

Figure 3. Inventory centralisation according to demand volume and criticality

At the other extreme the least critical slow moving products (DC segment) should be *make-to-order* (MTO) as these products can be substituted by other more 'critical' decentralised products in the case of an emergency. In effect DC products would only ever be used for planned procedures associated with specific patients. Between the extremes described above there are intermediary strategies best described using the segmented supply chain illustration in figure 4. Following the method of Flores and Whybark (1986), segments are aggregated into management groups and, using a logical argument to minimise the risk of wastage, assigned to one of four supply chain strategies / supply chain structures as follows:

Lean Supply Chain Strategy 1: Make-to-Stock 2-cycle. All critical fast moving products (VA and VB) except those with short-shelf-life (<15 days); all frozen long shelf-life products in segments VC, EA and EB segments. Twice daily routine replenishment and de-coupling at RIE with safety stocks to cover the uncertainty in daily forecasts will ensure minimal wastage. A central riskpool to cover uncertainty in national demand should be held in the SNBTS blood bank, but this stock should exclude short-shelf life products to minimise the risk of wastage due to outage.

Lean Supply Chain Strategy 2: Make-to-Stock 1-cycle. All EA, EB and DA products as well as the short-shelf life products excluded from Strategy 1. Similar to strategy 1, but without any central risk pool, i.e. products are pushed directly to RIE, ensuring availability with reduced inventory.

Leagile Supply Chain Strategy 3: Distribute-to-Order. Remaining VC, all DB and all frozen DA, EC and DC products. The supply chain is de-coupled at the SNBTS central blood bank. It is expected that on occasion ad hoc emergency deliveries may be necessary to meet a small proportion of demand for VC products. Riskpooling will reduce the risk of wastage.

Agile Supply Chain Strategy 4: Make-to-Order. Remaining EC and DC products. Although 15% of products are allocated to this strategy, they account for just 0.4% of demand. These make-to-order products would be ordered by RIE for specific planned procedures.

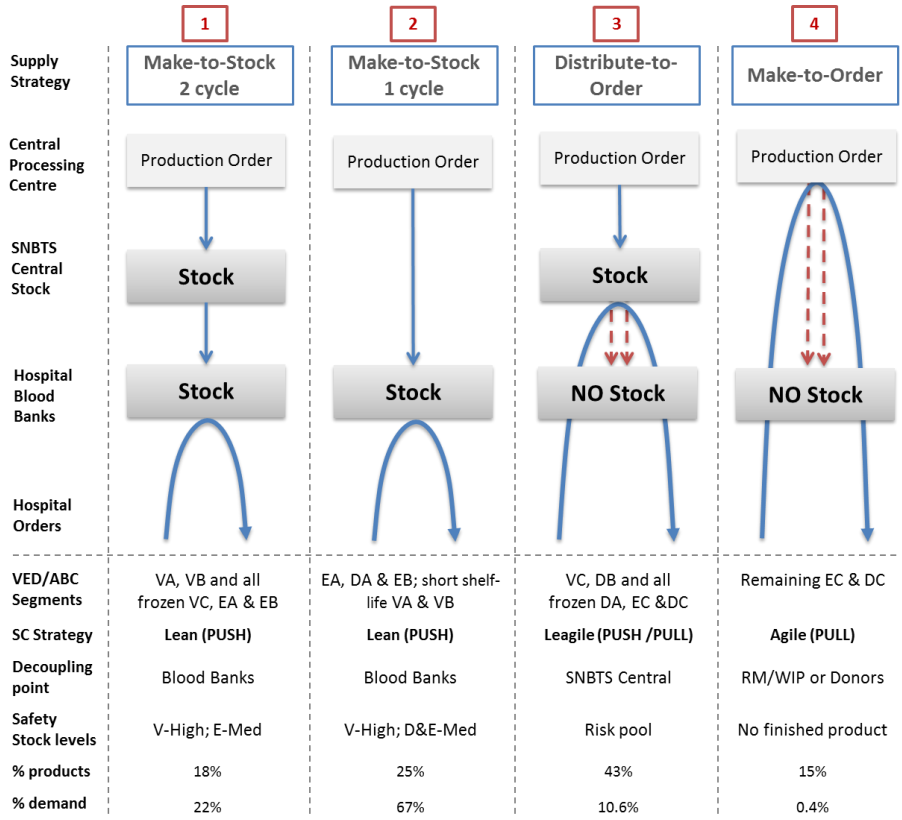

Figure 4. Assignment of ABC/VED segments to four supply chain strategies and associated supply chain structures serving the RIE blood Bank

Together Strategies 1 and 2 would serve 89% of RIE transfused demand directly from the RIE blood bank ensuring high availability of the most critical and fast moving products. The remaining 11% of RIE demand for slower moving and less critical products would be satisfied via a more agile approach from central stocks or on a MTO basis.

Conclusion

The paper has identified product criticality, defined in terms of product substitutability and compatibility, and demand volume as key drivers to be considered in the selection of supply chain strategy for blood products. Common criteria used in the commercial world such as cost value, product variety and product life cycle are less relevant in healthcare where the life-saving potential of products must take priority. A taxonomy for supply chain selection is proposed and using product and demand data for a large Scottish Blood Bank, RIE, its potential application has been explored. Using a logical argument product segments have been allocated to one of four possible supply chain strategies for RIE. Further work is necessary to extend the approach for remote blood banks and ultimately test application in a future pilot study.

Acknowledgements

This research was conducted as part of a Knowledge Transfer Partnership (KTP 9479) between Heriot-Watt University and the SNBTS, jointly funded by Innovate UK and the SNBTS.

References

- Aitken, J., Childerhouse, P., Christopher, M. & Towill, D. 2005. 'Designing and managing multiple pipelines'. *Journal of Business Logistics*, Vol. 26, pp. 73-96.
- Blackburn, J. & Scudder, G. 2009. 'Supply chain strategies for perishable products: the case of fresh produce'. Wiley Periodicals, Inc.
- Childerhouse, P., Aitken, J. & Towill, D. R. 2002. 'Analysis and design of focused demand chains'. *Journal of Operations Management*, Vol. 20, pp. 675-689.
- Christopher, M. & Peck, H. 1999. Marketing Logistics, Oxford, Butterworth-Heninemann.
- Christopher, M. & Towill, D. R. 2002. 'Developing Market Specific Supply Chain Strategies'. *The International Journal of Logistics Management*, Vol. 13, pp. 1-14.
- Currie, C. J., Patel, T. C., Mcewan, P. & Dixon, S. 2004. 'Evaluation of the future supply and demand for blood products in the United Kingdom National Health Service'. Transfusion Medicine, Vol. 14, pp. 19-24.
- Fisher, M. L. 1997b. 'What Is the Right Supply Chain for Your Product?' *Harvard business review*, Vol. 75, pp. 105-116.
- Flores, B. E. & Whybark, D. C. 1986. 'Multiple Criteria ABC Analysis'. *International Journal of Operations & Production Management*, Vol. 6, pp. 38-46.
- Godsell, J., Diefenbach, T., Clemmow, C., Towill, D. & Christopher, M. 2011. 'Enabling supply chain segmentation through demand profiling'. *International Journal of Physical Distribution & Logistics Management*, Vol. 41, pp. 296-314.
- Godsell, J., Harrison, A., Emberson, C. & Storey, J. 2006. 'Customer responsive supply chain strategy: An unnatural act?' *International Journal of Logistics Research and Applications*, Vol. 9, pp. 47-56.
- Harrison, A. & van Hoek, R. 2005. Logistics Management and Strategy, Hemel Hempstead, Prentice-Hall/Financial Times.
- Hübner, A. H., Kuhn, H. & Sternbeck, M. G. 2013. 'Demand and supply chain planning in grocery retail: an operations planning framework'. *International Journal of Retail & Distribution Management*, Vol. 41, pp. 512.
- Jüttner, U., Godsell, J. & Christopher, M. G. 2006. 'Demand chain alignment competence—delivering value through product life cycle management'. *Industrial Marketing Management*, Vol. 35, pp. 989-1001.
- Kittipanya-Ngam, P., Shi, Y. & Gregory, M. J. 2011. 'Exploring geographical dispersion in Thailand-based food supply chain (FSC)'. *Benchmarking: An International Journal*, Vol. 18, pp. 802-833.
- Lee, H. L. 2002. 'Aligning supply chain strategies with product uncertainties'. *California management review*, Vol. 44, pp. 105-119.
- Lovell, A., Saw, R. & Stimson, J. 2005. 'Product value-density: managing diversity through supply chain segmentation'. *The International Journal of Logistics Management*, Vol. 16, 142-158.
- Payne, T. & Peters, M. J. 2004. 'What is the right supply chain for your products?'. *The International Journal of Logistics Management*, Vol. 15, pp. 77-92.
- Rezaei, J. & Ortt, R. 2012. 'A multi-variable approach to supplier segmentation'. *International Journal of Production Research*, Vol. 50, pp. 4593-4611.
- Rutherford, C. & Woolford, R. 2005. 'The criticality of consumable spare parts: an inventory solution'. LRN Conference Proceedings.
- Saaty, T. L. 1990. 'How to make a decision - the analytic hierarchy process'. *European Journal of Operations Research*, Vol. 48, pp. 9-26.

- Sun, S. Y., Hsu, M. H. & Hwang, W. J. 2009. 'The impact of alignment between supply chain strategy and environmental uncertainty on SCM performance'. *Supply Chain Management: An International Journal*, Vol. 14, pp. 201-212.
- United Kingdom Blood Services 2013. Handbook of Transfusion Medicine, United Kingdom, The Stationary Office.
- Veldhuizen, I., Follea, G. & De Kort, W. 2013. 'Donor cycle and donor segmentation: New tools for improving blood donor management'. *Vox Sanguinis*, Vol. 105, pp. 28-37.
- Vonderembse, M. A., Uppal, M., Huang, S. H. & Dismukes, J. P. 2006. 'Designing supply chains: Towards theory development'. *International Journal of Production Economics*, Vol. 100, pp. 223-238.